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DEVELOPMENT OF A REMOTE OPERATION CAPABILITY FOR THE RAPID RUNWAY REPAIR (RRR) EXCAVATOR

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The objective of this project was to develop a system such that an operator could control a John Deere 690C excavator remotely while accomplishing RRR tasks. With this remote-control system, an operator is able to direct all functions of the excavator (propulsion, digging, compaction, leveling, etc.) from a control console located remotely from the vehicle. As such, an important element of the project is to provide the operator with sufficient sensory feedback so that the system can be effectively controlled. This report will document the hardware utilized in the project and the software developed for communication between the computer on-board the excavator and the control console computer. A video of the system demonstration has also been prepared and has been delivered to the Air Force technical program director separately from this report.

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PREFACE

This final report was prepared by University of Florida, Center of Intelligent Machines and Robotics, Department of Mechanical Engineering, Gainesville FL 32611, under Contract ID F08637-90-C-0024. This report is based on work completed June 1994.

This report describes the development and evaluation of a system where an operator can control a John Deere 690C excavator remotely while accomplishing RRR tasks. With this remote-control system, an operator can direct all functions of the excavator (propulsion, digging, compaction, leveling, etc.) from a control console located remotely from the vehicle. This report documents the hardware utilized in the project and the software developed for communication between the computer on-board the excavator and the control console computer.

The work was performed between October 1993 and June 1994. The project officer was Mr Allen D. Nease.

Table of Contents

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1. INTRODUCTION

The objective of this project was to develop a system such that an operator could control a John Deere 690C excavator remotely while accomplishing RRR tasks. With this remote-control system, an operator is able to direct all functions of the excavator (propulsion, digging, compaction, leveling, etc.) from a control console located remotely from the vehicle. As such, an important element of the project is to provide the operator with sufficient sensory feedback so that the system can be effectively controlled.

This report will document the hardware utilized in the project and the software developed for communication between the computer on-board the excavator and the control console computer. A video of the system demonstration has also been prepared and has been delivered to the Air Force technical program director separately from this report.

2. APPROACH

The objective of developing a remote control system was divided into the following four components:

1) control console design and fabrication
2) communication of the control panel status to the on-board computer
3) response of the excavator based upon the panel status
4) feedback of video images from the work site to the operator

Each of these four areas will be discussed subsequently.

2.1 Operational Assumptions

When the project was begun, two assumptions were made dealing with the operational scenario. First, it was assumed that the excavator engine would be started and thus it would not be necessary to perform this task remotely. Second, the on-board computer would be manually turned on and the interface software started. If the excavator engine was ever stopped during operation (as when the emergency stop button is pressed on the remote control panel), the operator would have to get in the excavator, restart the engine, reboot the on-board computer, and finally restart the interface software. Performing these tasks remotely as opposed to manually would have added cost to the project, with little added performance.

2.2 System Overview

Two computers are used in the system to establish open loop control of the remote excavator. One computer is located on-board the excavator and one is situated with the control console (see Figures 1 and 2). These computers handle communications, I/O, and the required computations. Specifically, the operator controls the excavator by manipulating the joysticks and switches on the control panel (the control panel is a subsystem of the control console). The control console computer constantly determines the status of all the devices and then communicates this information to the computer on-board the excavator. The excavator computer determines how the vehicle should respond based on the current control panel status and issues appropriate commands. For example, the panel status might show that the operator is pressing the left propel joystick forward. This fact is communicated to the on-board computer. This computer realizes that the hydraulic valve which controls the left wheels of the excavator must

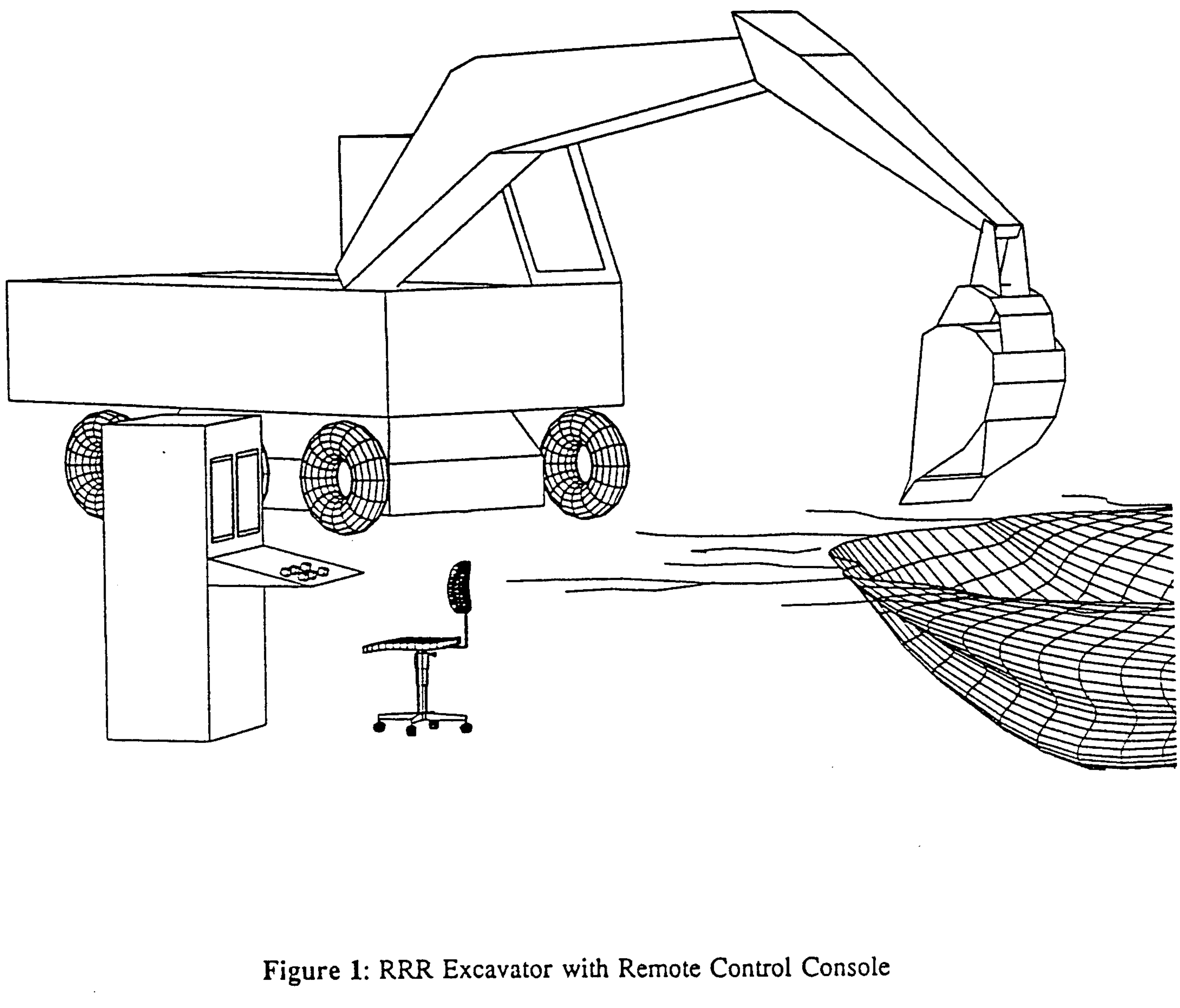

Figure 1: RRR Excavator with Remote Control Console

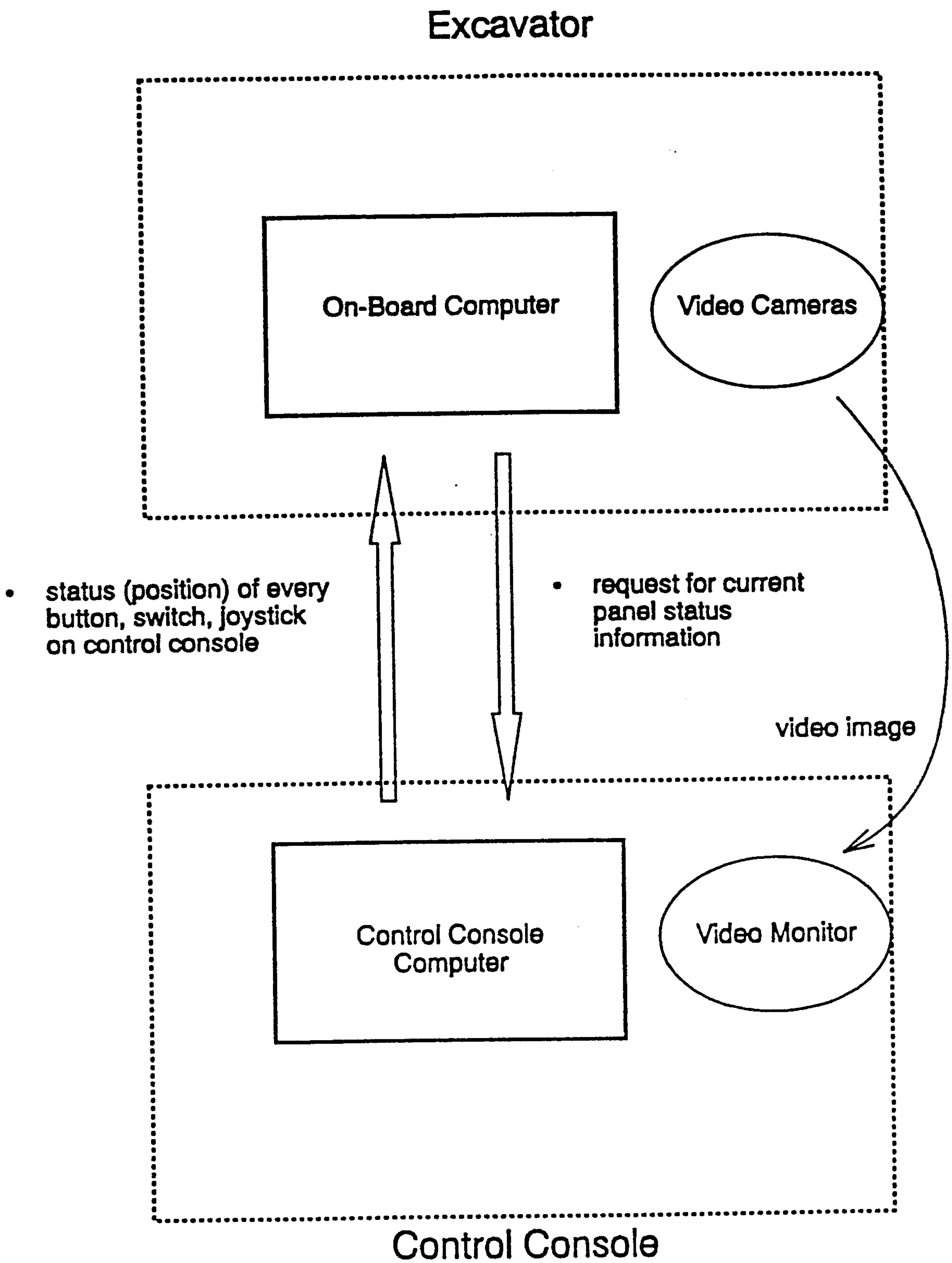

Figure 2: Information Flow

be opened more fully. An appropriate analog signal is generated to accomplish this task.

No low level feedback is communicated back to the operator. That is, no sensed joint angle positions, vehicle velocity measurements, etc. are returned to the operator. (It should be noted, however, that the communications scheme employed would allow for this reverse flow of information.) All feedback is accomplished via two video cameras which are mounted on the vehicle. One of the cameras is positioned on top of a pan/tilt mechanism which the operator can control remotely from the control console. The operator must drive the vehicle, and perform all crater repair tasks based solely on the images returned by the video system.

2.3 Control Console Design and Fabrication

The tasks which the operator can perform from the control console may be divided into the following three categories:

- Mobility functions. The operator is able to control the left and right wheel propel functions as well as the engine throttle.
- Action functions. These functions deal with the control of the four arm joint actuators, the leveling blade, tool trailer, and tool latching pin.
- Supervisory functions. These functions allow the operator to control the two video cameras and the one pan/tilt mechanism.

A drawing of the control console is shown in Figure 3. As shown in the figure, the console consists of a pair of racks in which a rack mountable computer, a TV monitor, and a control panel are mounted. The TV monitor displays the video scenario at the operating site. The control panel has 7 momentary three-position rocker switches, one on-off rocker switch, two

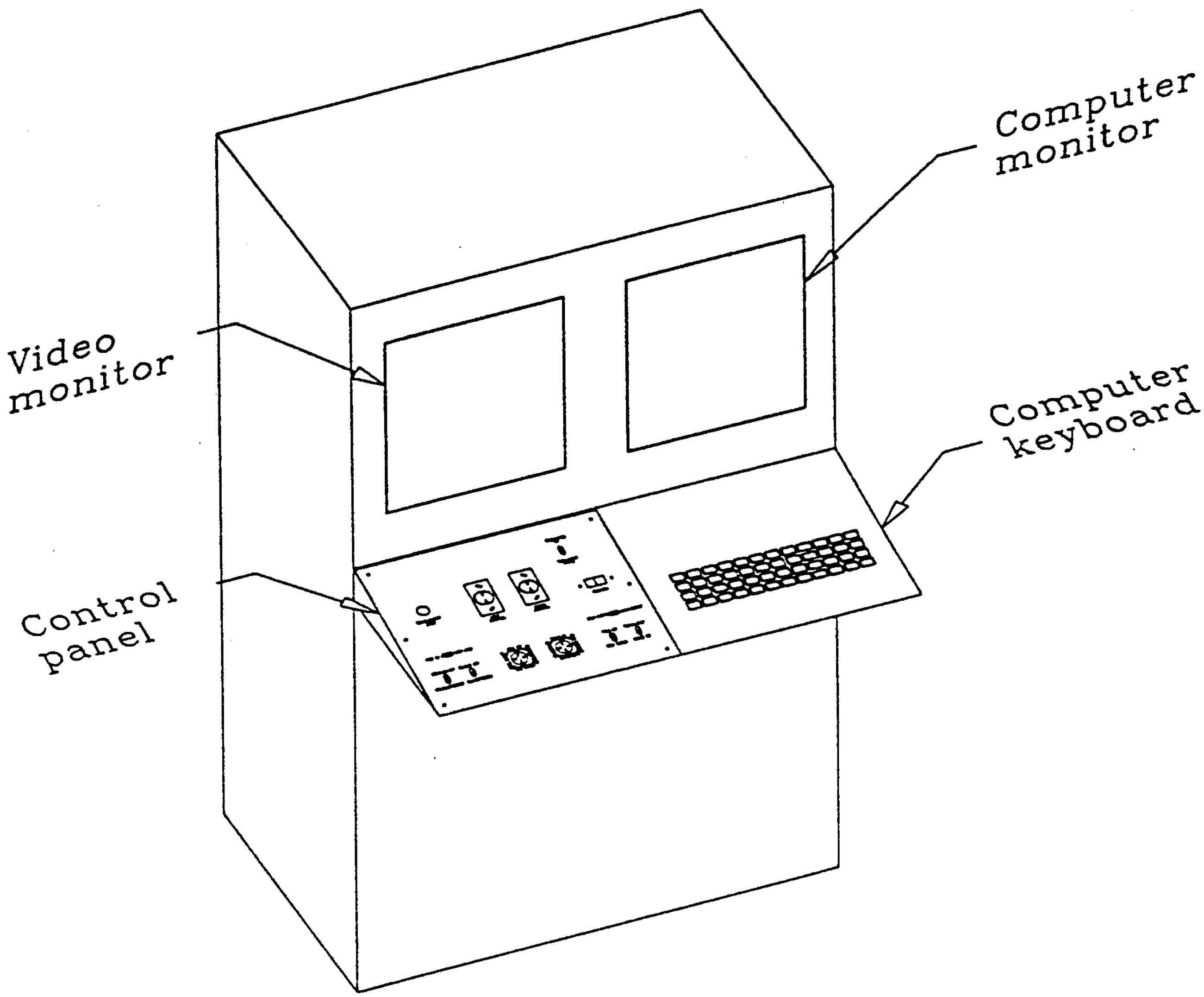

Figure 3: Control Console

single-axis joysticks, and two dual-axis joysticks to control the excavator. A drawing of the layout of the control panel is shown in Figure 4.

An Industrial Computer Source ICS-286 rack mountable computer is mounted in the rack of the console. One digital I/O, CIO-DIO24 from Cyber Research, and one DT2821 board are installed in the console computer. The digital I/O board, with the base address of 0x300, reads discrete signals of switching actions. The switches and button receive the necessary +5 VDC power from the ICS-286 computer through the CIO-DIO24 digital I/O interface. A DT2821 board, with the base address 0x240, reads the analog outputs from the joysticks. A/D channels 0, 2, 4, and 6 are connected to the dual-axis joysticks to actuate swing, boom, arm, and bucket, respectively. A/D channels 8 and 10 are connected to the single-axis joysticks, respectively, to drive the left and right propels. Analog signals are single-ended connected to the terminal strip.

It is important to note that the A/D channels of the DT2821 can only take up to ± 10 VDC. The output voltages from the joysticks must therefore be adjusted to fit into this range. The potentiometers of the dual-axis joysticks turn only a fraction of their full ranges for the travelling angles. Thus, they work well with the 15 VDC power supplied by the DT2821 interface. The travelling angles for the single-axis joysticks almost span the full range of their attached potentiometers, however. A trimming potentiometer is used adjust the voltage outputs to within ± 10 VDC.

As previously stated, the switches and the button take +5 VDC from the CIO-DIO24. All the switches on the control panel are normally open except for the emergency button and the two-position rocker switch. To avoid drawing too much current when any of the switches is closed, a 500 ohm resistor is used with each of the switches and the button. A resistor with

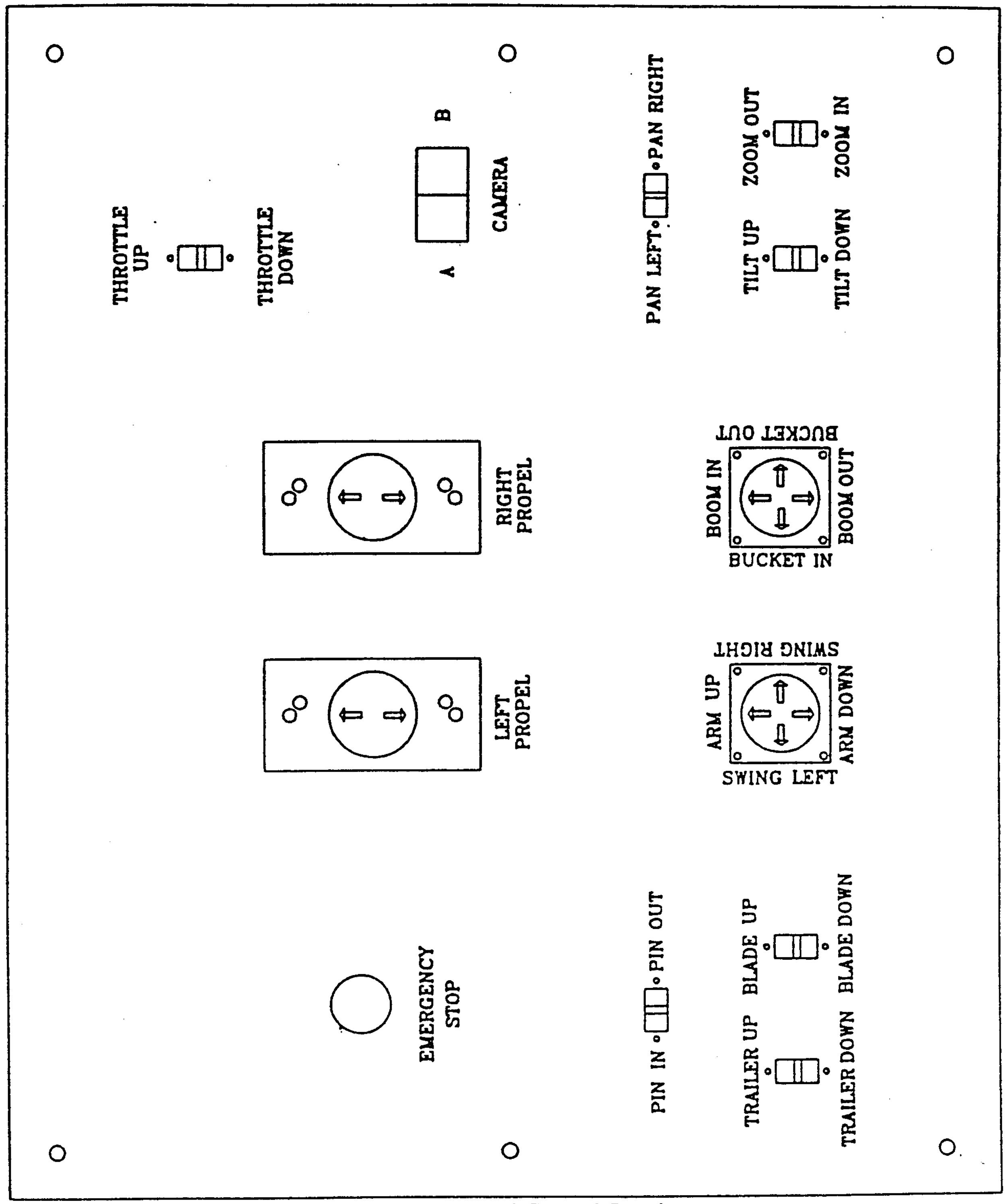

Figure 4: Layout of Control Panel

larger resistance would draw less current from the computer power supply. The limit of the value of the resistor which can be used is determined by the sensitivity of the digital I/O interface. The computer could not detect the changed status of a switch if too little current was drawn by the I/O channels. The schematic diagram of the wiring for the control panel is shown in Figure 5.

The joysticks on the control panel duplicate the functions of the control levers for the arm and the foot pedals for driving the excavator. This facilitates an experienced operator of the excavator while manipulating the teleoperation system. Proportional control is used for all the joystick controls.

The two-position rocker switch was installed to toggle between two cameras. It was not used in the project, although the wiring is operational and toggling the switch is detected by the console computer. Similarly, pressing of the emergency button is detected by the console computer, although a separate kill button was used for the excavator in place of this button on the panel.

The other momentary three-position switches can be grouped into two sets: those for the action functions and those for the video system. On the left-hand side of the control panel, there is (a) one switch used for pushing in or out the tool latching pin at the end of boom, (b) one for trailer up and trailer down, and (c) one for blade up and down. On the right-hand side of the control panel, there is (a) one switch used for panning camera A left and right, (b) one for tilting camera A up and down, and (c) one for zooming in and out for camera A. The technical manual for the cameras has been ordered, but has yet to be received. As such, the zooming function has not been implemented, although the console computer does detect when the switch is pressed.

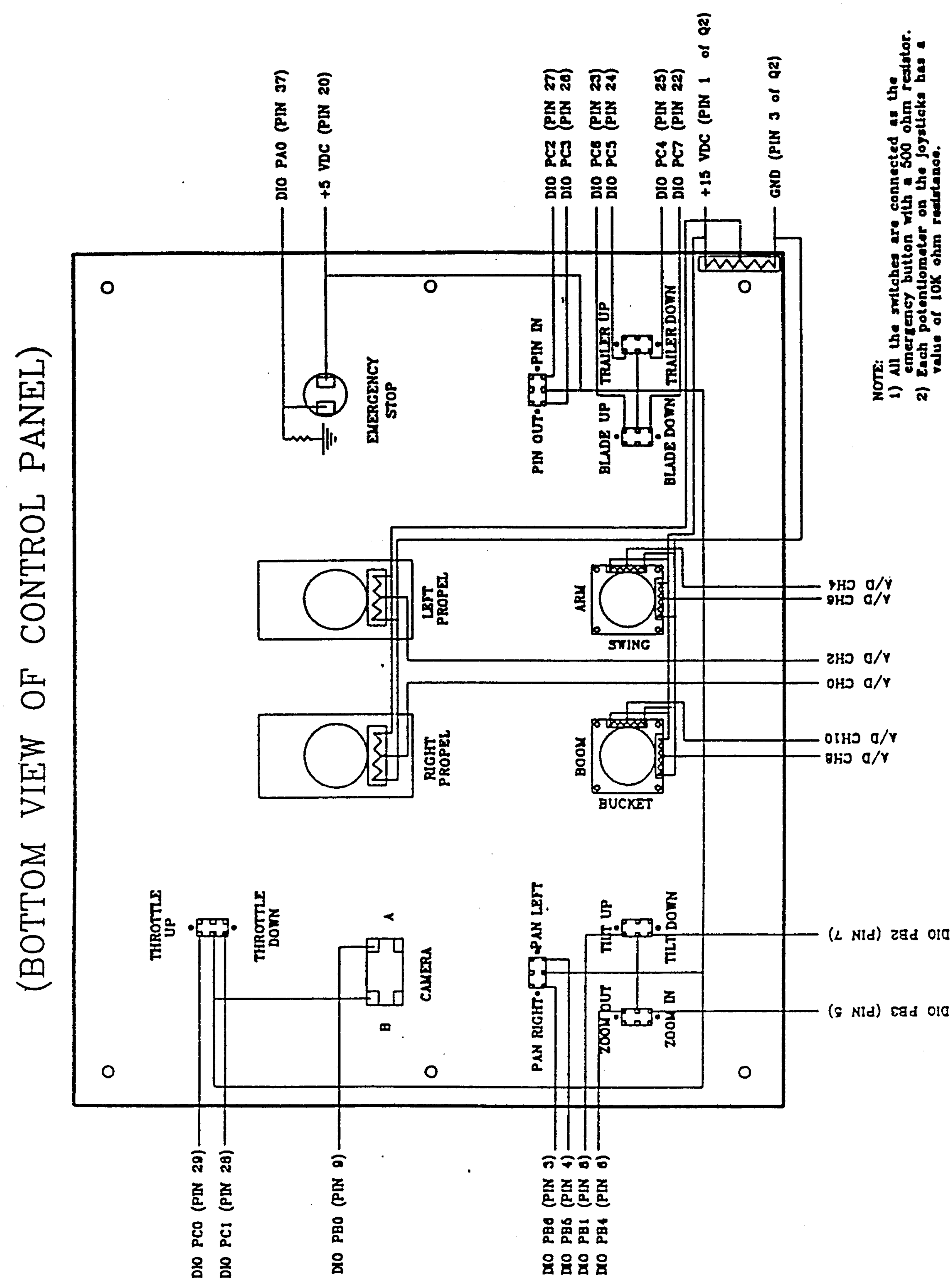

Figure 5: Wiring Diagram for Control Panel

2.4 Excavator Control

A KMS-386 industrial computer is used in the excavator. The KMS-386 requires +24 VDC power. The current status of the control panel (the binary status of every button and switch and the analogue status of each joystick) is communicated from the control console to the on-board computer via a serial communications link (see Section 2.5). The KMS-386 computer must control the various actuators on the excavator in response to the current panel status.

Three Data Translation DT2821 I/O interfaces and one Metrabyte DDA-06 board are installed in the on-board computer. Although each DT2821 is capable of doing 8 differential A/D conversions or 16 single-ended A/D conversions, 2 D/A conversions, and 16 digital I/O, only six D/A channels are required for this stage of the project. A/D and D/A conversions both have 12-bit resolution. The first two DT2821 cards, with base addresses of 0x240 and 0x280, respectively, are used to control the motions of the swing, arm, boom, and bucket. The D/A channels of the third DT2821 card, with base address of 0x2C0, are used to drive the left and right propels. Each DT2821 card is connected to a DT707 data terminal board to facilitate wiring (see Figure 6).

A digital I/O board, DDA-06 from Metrabyte, is used to control the pan/tilt mechanism used with camera A. The DDA-06 sends out discrete signals to an ERB-24 relay board to actuate the motions according to the instructions from the control panel. The base address of the DDA-06 is 0x300. Since the ERB-24 needs 110 VAC power, it is connected to a 24 VDC/110 VAC invertor. The schematic diagram for the wiring of the ERB-24 is shown as Figure 7.

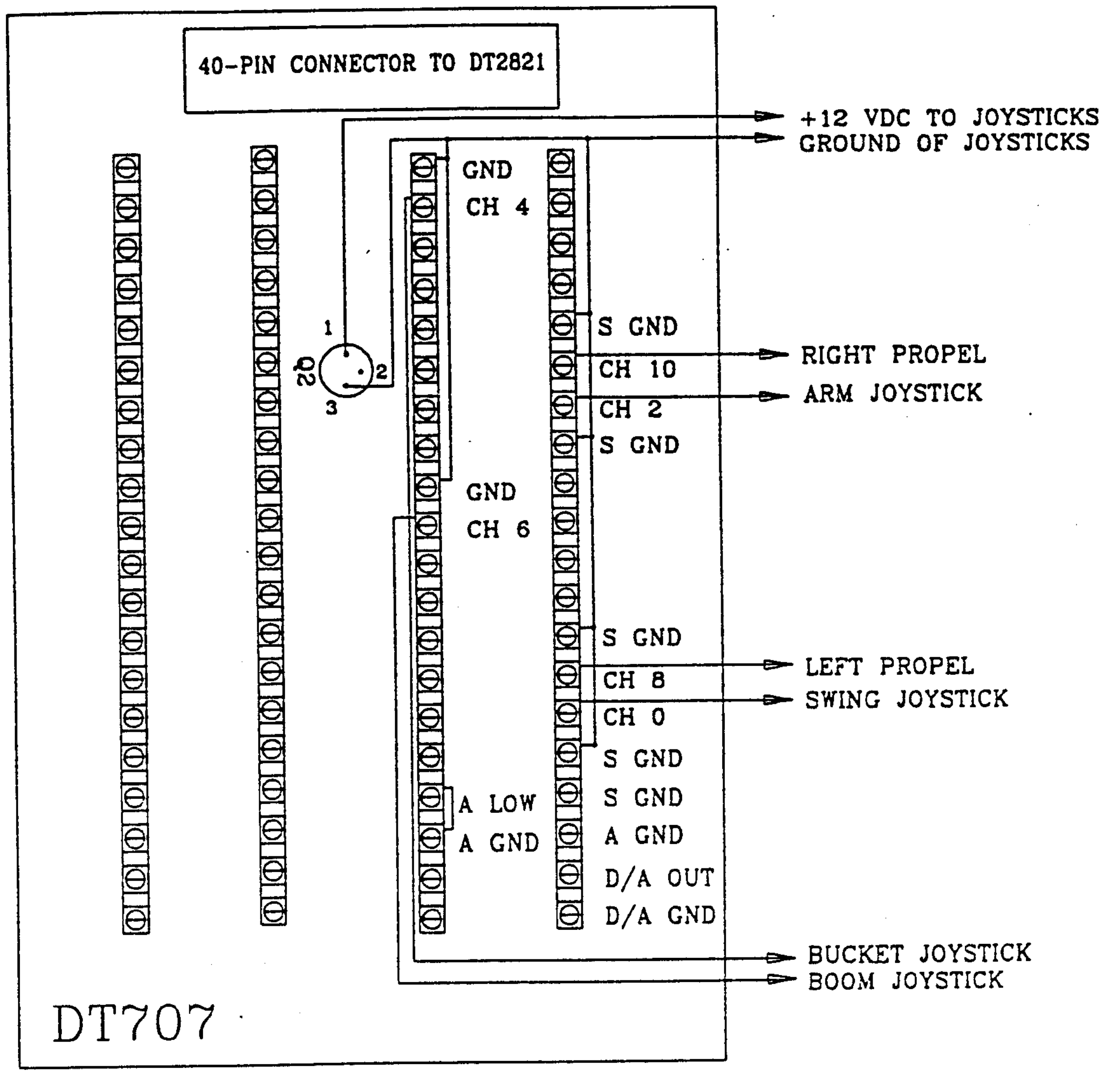

Figure 6: Wiring diagram for DT707 Data Terminal

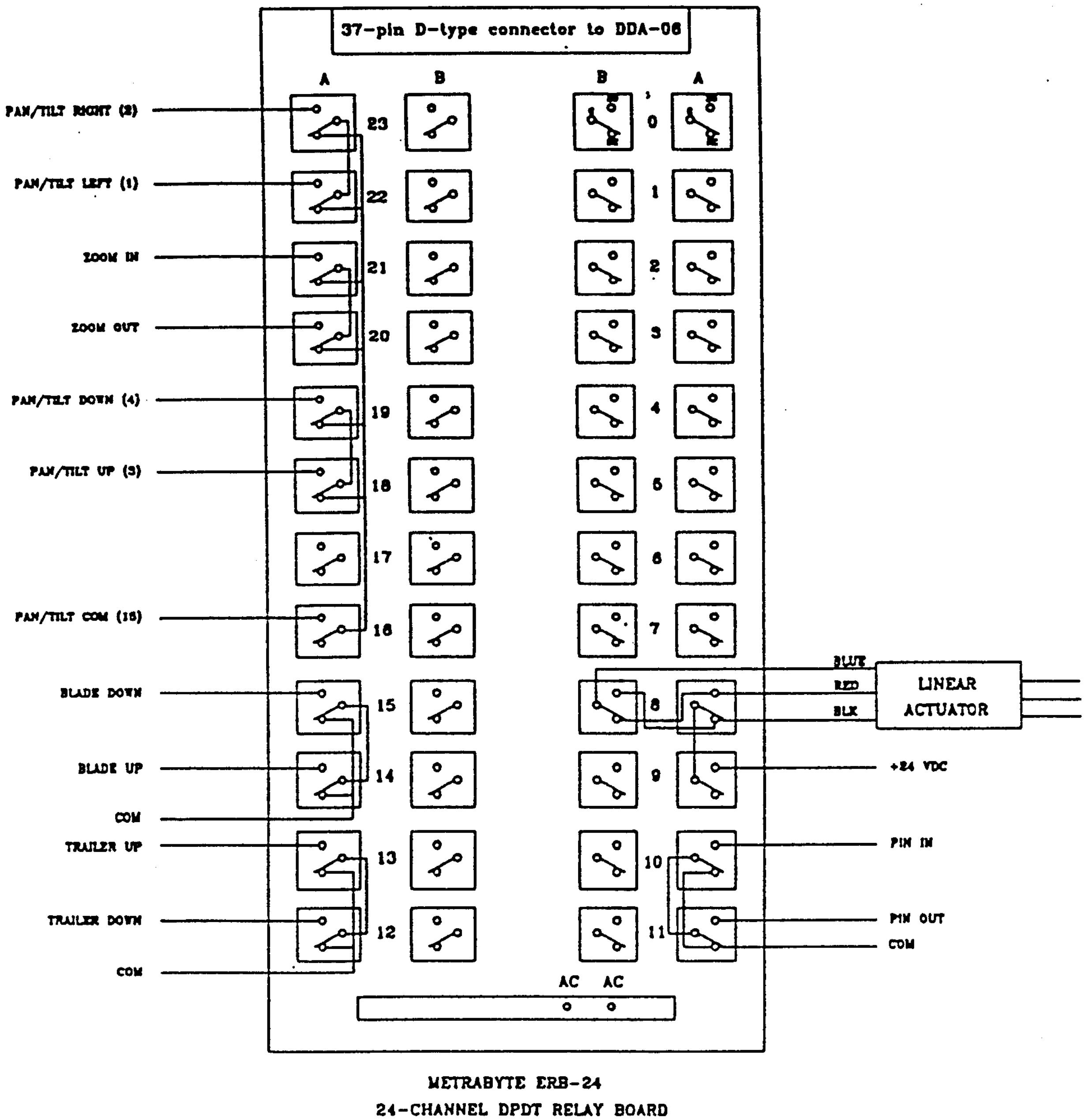

Figure 7: Schematic Diagram for the Wiring of the ERB-24 Relay Board

2.5 Communications

Serial communications was established between the ICS-286 computer (console computer) and the KMS-386 computer (on-board computer). The COM1 port was used on each of the computers. The original proposal called for radio communication between the computers via a pair of radio modems at a speed of 1200 baud.

The modems were successfully installed and tested in the CIMAR laboratory. However, due to a lack of frequency clearance, the radio modems could not be used at Tyndall Air Force Base. It was proposed that the excavator be tethered. Normal serial communications via wire, however, is designed for a distance of 50 ft. A pair of Inmac data drivers were used to increase the allowable length of the communications tether. Data drivers can reach 3.3 miles at 9600 baud with 24 gauge wires.

Each data driver uses two pairs of wires for communication, one pair for transmitting data and another pair for receiving data. The control sequence is identical to that used for regular RS-232C serial communication. Although it is a bit cumbersome to have communication through tethered cables, the communication speed of 9600 baud, was eight times faster than could be achieved with the radio modems.

The communications software, coded in Turbo C, was created with hardware interrupt driven functions so that a tight communication loop could be established. The communication sequence starts with the program "CONTROL" on the excavator side. When the program "CONTROL" is executed, it waits for a prompt to synchronize the communications. At this point, the operator can start the program "PANEL" on the console computer. It sends out a synchronization prompt, and then waits for another synchronization prompt to return from the

excavator. After the synchronization process has completed, a message "Synchronized..." is displayed on the control console monitor indicating that proper communication is now established. Program "PANEL" then reads the status of all switches, buttons, and joysticks and sends this information to the on-board computer.

Sixteen bytes of data are passed for each transmission cycle (see Figure 8). The first byte is currently used to stop the control sequence, although its function can be expanded to instruct multiple vehicles. The next three bytes are used to control the relays on the ERB-24 which control the pan/tilt mechanism for camera A. The remainder of the bytes are used to indicate the status of the switches, buttons, and joysticks. A time-out feature is also incorporated in the software in order to halt the excavator if the panel status has not been communicated from the console computer within a specified time interval. The communications programs have been delivered to Tyndall Air Force Base separate from this report.

2.6 Video Feedback System

Two SONY DXC-325 CCD color video cameras are used to send video images to the control console so that the operator can view the scene at the remote site. Camera A is mounted on a pan/tilt mechanism on the top of cab. The pan/tilt mechanism can tilt up 15° and down 60° at a speed of 3.0° per second. It can also pan through a range of 330° at a speed of 7.2° per second. A wiring diagram for the pan/tilt mechanism is shown in Figure 9. Camera B is mounted on the side the excavator and is aimed toward the arm in order to aid the operator in digging operations. Both cameras require +12 VDC from an invertor.

Originally, the video signals from the cameras were to be sent to the control console by

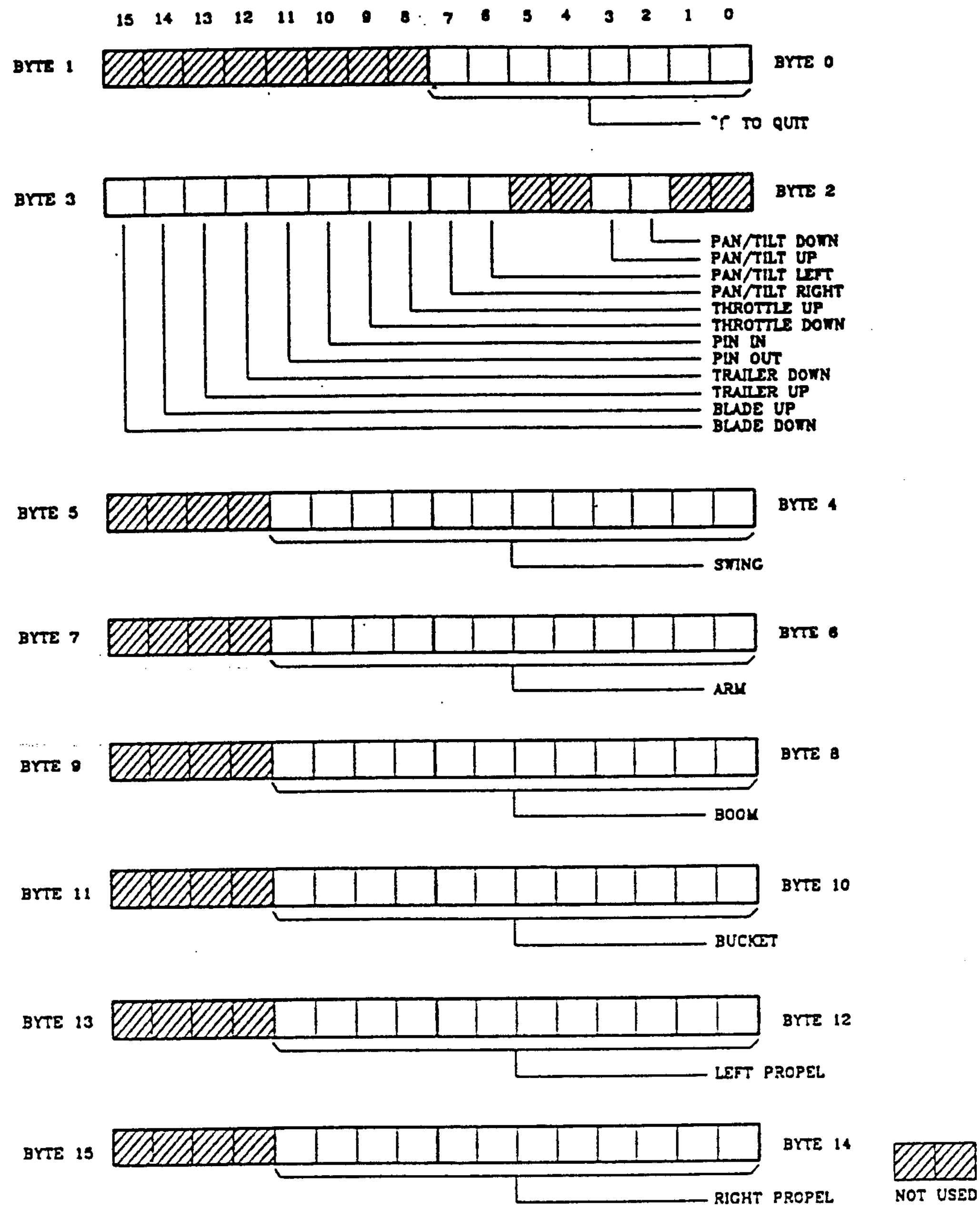

Figure 8: Organization of Serial Communication Packet

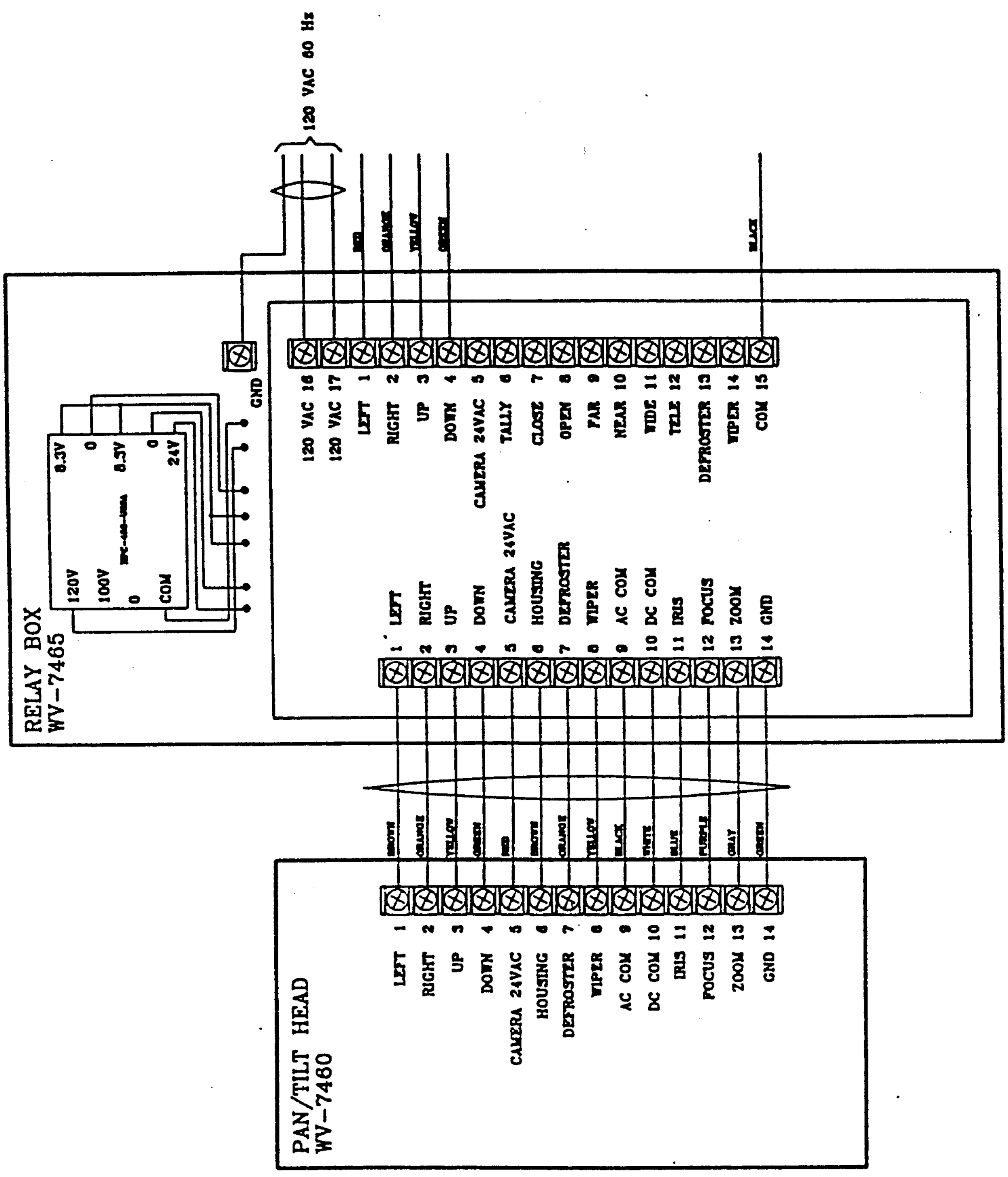

Figure 9: Wiring Diagram for the Pan/Tilt Mechanism

means of a video transmitter and receiver. However, since frequency clearance could not be obtained, the video signals from the cameras were sent to the console through a pair of coaxial cables. Both cables connect directly to the console monitor. The operator can select the desired camera by pressing a selector switch on the monitor itself.

3. SYSTEM DEMONSTRATION

On June 4, 1991, a successful demonstration took place at Tyndall Air Force Base. All the designed functions of the added system for the JD690C excavator worked properly. Although maneuvering the remote excavator was not a simple task for an inexperienced operator, an experienced operator was able to efficiently maneuver the excavator, and perform a variety of crater repair tasks.

4. CONCLUSION AND RECOMMENDATIONS

Certain modifications can be made to the system to improve its performance. The following comments/recommendations are made:

1) The maximum flow capacity of the hydraulic system of the JD690C is apparently not large enough to support the full simultaneous operation of the arm actuators. Drifting of the arms has been observed when more than one joint is moved. In the developed system, the trailer is able to be lifted by the switching action, but the hydraulic system is not powerful enough to hold it in place. A solution to these problems is to carefully calculate the required flow volume at the vehicle design stage in order to cover the full extent of system operation. It would be very difficult and expensive to modify the existing excavator, however. (It should be noted that the

problem with the availability of fluid flow is not due in any part to this effort of developing a remote operator's console. The same problem exists when an operator is in the cab.)

2) When the operator is driving the excavator, the only feedback is the images provided by the two video cameras on the excavator. The cameras offer a limited view of the remote site. The video system also falls short in conveying the location of the excavator in world coordinates. It could be possible for the operator to become disoriented. An improvement to the system would result if global excavator coordinates were known and displayed for the operator on a top down view map of the environment. Global excavator coordinates are not currently determined, but future efforts in navigation will provide this data.

3) Audio feedback from the operating site can also be helpful to the operator in understanding the situation. Engine noise, etc. provides a good indication of the situation at the remote site.

4) It is not economical or practical to install cameras all around the vehicle. Yet the operator may require a "bird's-eye-view" in order to visualize the excavator status (blade up/down, arm configuration, tool trailer up/down, etc.) A graphic display of the remote vehicle which uses the feedback joint angles, trailer position, etc. and the global coordinates of the vehicle in the working environment would be helpful.

5) In the current system, there is no feedback from the pan/tilt mechanism. It is not easy for the operator to orient the view presented on the monitor with respect to the excavator.

6) The throttle control will be better if there is feedback to show the position of the linear actuator.

7) Tethered cables could impede the movement of the excavator. Radio communication should be used for the runway repair vehicle.